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System Design and Applications of the Ultra Small Aperture Terminal With the Advanced Communications Technology Satellite

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SYSTEM DESIGN AND APPLICATIONS OF THE ULTRA SMALL APERTURE TERMINAL WITH THE ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE

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Abstract
NASA's Advanced Communications Technology Satellite (ACTS), is demonstrating new technologies in communication systems at Ka-Band. One such technology is small size ground stations capable of modest data rates for interactive communications. Industry has shown interest in these small terminals for the commercial and consumer markets. The advanced technologies of Ka-Band systems such as high gain spot beams allow user ground stations to carry acceptable traffic with small antenna's and low power transmitters resulting in lower cost satellite ground stations.

The Lewis Research Center's Space Communications Program has developed small ground stations referred to as an Ultra Small Aperture Terminal (USAT) available for use by experimenters to use the ACTS satellite for technology development and demonstration. The Ultra Small Aperture Terminal consists of a 35cm or 60 cm antenna, solid state power amplifiers (SSPA) ranging from ¼ Watt to 4 Watt, 4.0 dB noise figure receivers, a 70 Mhz user interface, and the necessary upconverter and downconverter equipment for proper frequency translation to Ka-band.

Once thought suitable only for low kilobit data rate applications such as Supervisory Control and Data Acquisition (SCADA), the USAT has proven to be an excellent choice for higher rate applications including broadcast video, full duplex video conferencing, remote telemedicine, ISDN voice and video communication, high speed data transfers (receive mode), Internet access from remote locations, and others. Demonstrations of these point-to-point applications conducted by NASA with various organizations have used data rates from 76 kbps up to 8 Mbps. This report summarizes the current architecture used by the USAT and describes several applications using the terminal.

Introduction
As the commercial Ka-band satellite systems continue to mature in the US industry, NASA continues to provide a platform to test, characterize, and understand emerging technologies critical to these future Ka-band systems. NASA launched the ACTS satellite in September, 1993. ACTS was the first Ka-band satellite available to the U.S. commercial satellite communications industry for testing and experiments. Several key high risk technologies were launched on the spacecraft including high gain spot beam antennas, on-board baseband processor, and wideband transponders. Although standard commercial satellites are not intended to carry all the technologies as ACTS, the goal was for industry to access the different technologies so that they could evaluate which technologies would be successful for commercial systems. In addition to satellite technologies at Ka-band, NASA also developed an aggressive Ka-band ground station program with capabilities consisting of both very small (35cm antenna) and large ground stations (5m antenna).

One such technology where NASA is providing important information is in the area of small terminal technology and development. Over the past few years NASA's Lewis Research Center, Cleveland, Ohio, has developed small consumer size ground stations referred to as Ultra Small Aperture Terminals which refer to the 35cm or 60cm diameter antenna often used with the small stations. The ground station specifications were developed by NASA and individual components manufactured by U.S. companies. NASA conducted the final integration and testing of the stations. The terminals provide a platform for government and industry experimenters to use the ACTS satellite and become familiar with the advantages and challenges of small satellite ground stations at Ka-Band.

The USAT ground stations were originally designed to communicate at kbps data rates for Supervisory Control and Data Acquisition applications for utility companies with remote monitoring requirements. Often remote locations are not accessible by traditional terrestrial lines or it is not cost effective to install terrestrial lines in situations such as mountainous regions or over long distances to few sites. Satellites become a viable solution to such systems and applications. In addition to utility type applications, industry has conducted experiments with NASA's small terminals for remote telemedicine, video conferencing, and distance learning among others. The ACTS USAT program has seen the number of applications for small terminals dramatically increase due to the small size, simplistic design, low power consumption, and performance of the stations.

Ground Station Architecture

The USAT ground stations are modular designed for easy configuration and integration. Consisting of five major subsystems, the ground station is easily assembled, operated, and serviced. Figure 1 illustrates the block diagram of the current USAT ground station. The USAT subsystems are the antenna (35cm, 60cm), combined low noise receiver/downconverter, combined upconverter and solid state power amplifier, intermediate frequency upconverter, and oscillator subsystem (up/down converter local oscillators and system reference oscillator).

The low noise downconverter (LND) is a custom designed low noise amplifier and downconverter system. The LND connects directly to the antenna OMT to receive and downconvert signals from 20 Ghz to 70 Mhz. The low noise downconverter was designed with a 4 dB noise figure and 26 dB gain. The LND measures 3.5"x2"x.5".

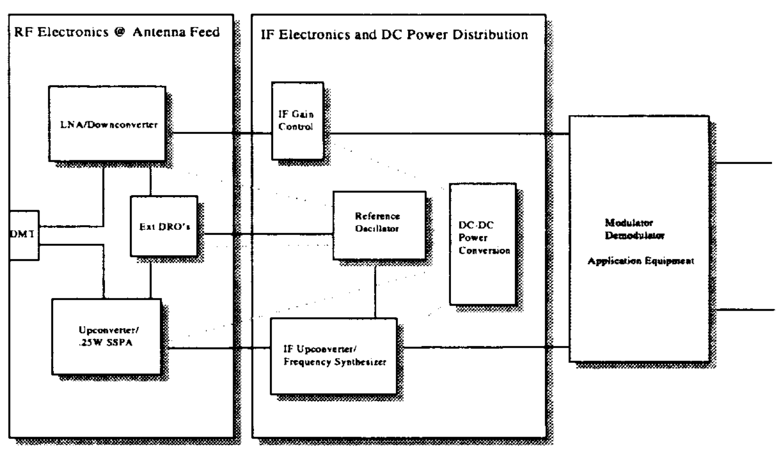

Figure 1 Ultra Small Aperture Terminal Block Diagram

The high power upconverter is also custom designed to combine the second stage upconversion (from UHF to Ka-Band @ 30 Ghz) with a quarter watt solid state power amplifier. Subsequent work and experiments with these terminals have also included the use of higher output solid state power amplifiers from one to four watts. The HPU measures approximately 5"x1.75"x.75".

The size of the standard antenna's used with the USAT ground stations are 35cm and 60cm, although a 1.2m is sometimes used based on link requirements for a specific application. Each antenna can mount to a non-penetrating roof mount (NPRM) base or tripod mount. All configurations use an offset feed configuration with a portion of the electronics mounted at the feed location. The remaining electronics or IF portion is mounted separately on the mast of the NPRM.

The enclosure at the antenna feed houses the LND, HPU, and up/down converter local oscillators. The IF electronics housing contains the first stage upconversion from 70 Mhz to UHF, the system reference oscillator and the dc-to-dc power distribution system used in the system. The entire ground station operates from +48 Vdc power with < 2 Amps. Figure 2 shows a picture of a fully assembled USAT ground station in its current configuration.

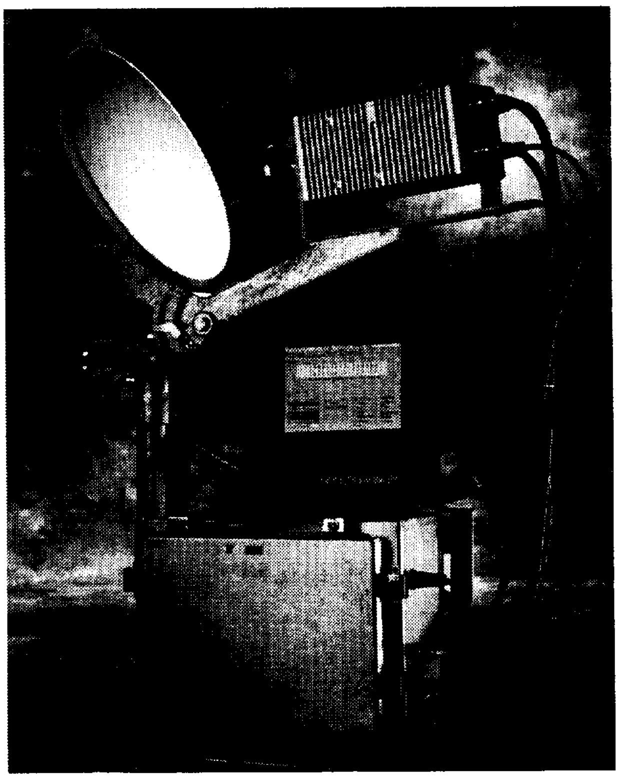

Figure 2 - Fully Assemble USAT Ground Station, (Laptop computer shown for reference)

Applications

Over the past few years, the ACTS Project Office at NASA Lewis Research Center along with industry partnership conducted a number of presentations to demonstrate the capability of the small Ka-band ground stations to the satellite communication industry including satellite communication system designers, communication system providers, Ka-band component developers, application equipment developers, and others. End users including the medical community, educational institutes, large and small corporations using satellite systems, and the general public also benefit from demonstrations by understanding where technology is headed, what services will be available in the future, and what costs and challenges these new services present.

Several of the demonstrations conducted over the past two years are presented. Each highlights certain applications or unique configurations available from the ACTS satellite. All the demonstrations were conducted in the microwave switch mode (MSM) of ACTS operation. The MSM mode is a "bent pipe" configuration with a static connection between two beams of the satellite. Each demonstration used a 4 Watt solid state power amplifier with either a .6m antenna or the 1.2m antenna (when using the ACTS steerable antenna), unless noted.

Telemedicine Demonstration - Frontier Community, Billings, Montana, July, 1996

Rural communities throughout the U.S. and under developed counties around the world all share a common challenge; access to current technology and trained specialists for medical conditions, diagnostics, and treatments. As the boom in telecommunications continues throughout the world, these under serviced areas are considered ideal markets for small satellite ground stations. Developing a hard wired communication infrastructure in under developed or mountainous areas is often costly due to small, sparsely separated populations. The small ground stations instantly links these areas to a nearby major metropolis or remote cities around the world in a much more cost effective manner than traditional wired communication systems.

In July, 1996 NASA Lewis Research Center in association with the NASA Johnson Space Center, Krug Life Sciences, St. Vincent Medical Center at Billings, Exxon Corporation, and the Crow-Northern Cheyenne Hospital, an affiliate hospital of the Indian Health Service (IHS), conducted two major telemedicine demonstrations in the state of Montana. The areas surrounding Billings, Montana is considered a frontier community. Access to certain areas is often difficult where roads are not always available or long distances require significant travel time. Helicopter flights are a normal part of the emergency response system for St. Vincent Medical Center incurring large transportation costs. Helicopters are even used to transport patients between St. Vincent's Medical Center and the Crow-Northern Cheyenne Hospital due to the distances between the centers.

NASA Johnson Space Center and Krug Life Sciences developed a small suitcase size medical instrument for possible future use on the shuttle. The Telemedicine Instrumentation Package or TIP, consisted of several medical instruments including an opthalmoscope, otoscope, an electrocardiogram, blood gas content detector, electronic stethoscope, and special camera for dermatology examinations. Figure 3 shows the TIP at the Exxon Occupational Medical Facility. The TIP includes a small video monitor mounted inside the unit to externally view the opthalmoscope, otoscope, and dermatology cameras.

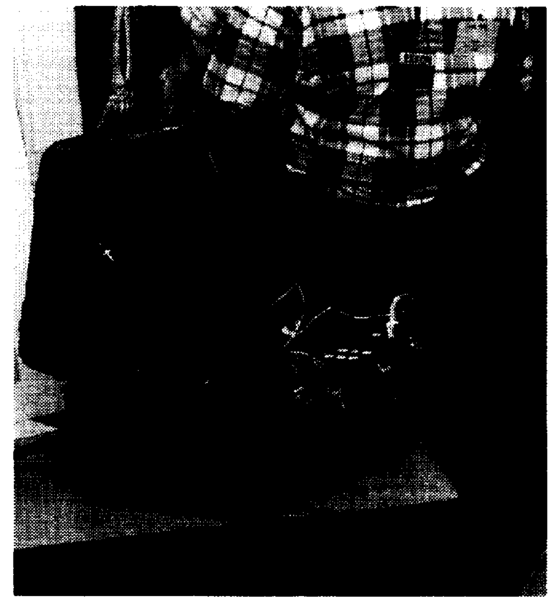

Figure 3 Telemedicine Instrumentation Package (TIP)

All the instruments are connected to the serial and video outputs of the TIP package. The demonstration was an ideal situation to field test two new NASA sponsored technologies; the newly developed remote medical package and Ka-band satellite technology. The location of the demonstration, Montana, posed several technical challenges due to the design of the ACTS satellite. The ACTS satellite has dedicated spot beams over most major metropolises throughout the U.S. Unfortunately, Montana does not have a dedicated spot beam. For those locations not serviced by a dedicated spot beam, the ACTS satellite uses its steerable antenna which is able to move to any location visible from the satellite. In this case the steerable beam was moved to point over Billings, Montana. The challenge in using the steerable is that the gain of the antenna is approximately 8-10 dB lower than a dedicated spot because of the size of the reflector on the spacecraft. Because the demonstrations planned to evaluate video quality up to T1 data rate, minor modifications were made to the USAT and the satellite configuration to support the desired data rates with sufficient margin for a successful demonstration.

The modifications to the USAT included a) using a 1.2m antenna at St. Vincent Medical Center, and b) using a 20 watt amplifier with the .6m antenna at the remote site. Typically, the USAT requires only a 1 to 4 watt transmitter. The additional power was necessary to support the T1 data rate using the steerable antenna and still provide adequate link margin. In addition, the satellite was configured to connect each USAT to the Link Evaluation Terminal in Cleveland instead of connecting directly to each other. This routes signals from one USAT in Montana to the LET in Cleveland then back to the second USAT in Montana. This results in the signal traveling to the satellite two times before reaching its final destination. This is referred to as a double hop because there are two hops to the satellite to get the signal from source to destination. Although this presented a more unique configuration of the satellite, it provided a more robust link for the demonstration without impacting the quality of the demonstration.

Both the Exxon Refinery demonstration and the Crow-Northern Cheyenne Hospital demonstration used the same ground station configuration. The indoor equipment at each location was similar consisting of a satellite modem, audio/video codec, and appropriate cameras and monitors. The remote station also included the TIP which was connected to the USAT via the a/v codec. The T1 satellite channel consisted of 23 - 64 kbps channels of video and 1-64 kbps channel of data from the TIP. The received video was routed to a monitor for viewing while the data stream was connected to a laptop computer for EKG and blood gas data display. The two signals were multiplexed together to form a single T1 data stream over the satellite. Figure 4 illustrates the ground station configuration and signal flow for the double hop from one USAT to another.

The remote side of the demonstrations took place at Exxon Corporation Refinery on-site Occupational Medical Center and Crow-Northern Cheyenne Hospital. St. Vincent Medical Center at Billings served as the physician site for both demonstrations. Several staged traumas were depicted in both demonstrations where the attending medical examiner consulted with personnel from St. Vincent's to determine if transportation to the facility at Billings was required for the particular circumstances. The telemedicine consults help reduce transportation costs and lost work time by eliminating those transfers that the primary physicians determines are not necessary. In some instances the attending practitioner may have transported a patient whose conditions were borderline but conservatively transported the person anyway. This also provides improved emergency response by having the primary physician available sooner while waiting for transportation. The video link between hospitals also allows physicians to conduct video consultations, share x-ray's and other video media, and make remote consults more productive than using the telephone alone. Personnel from the Crow-Northern Cheyenne Hospital also pointed out that the same technology could link their remote clinics back to their hospital in much the same way they were linked to St. Vincent's Medical Center during the demonstration. This would improve the level of care provided at the remote medical clinics in the Indian reservation and improve medical care throughout the reservation independent of geographic location.

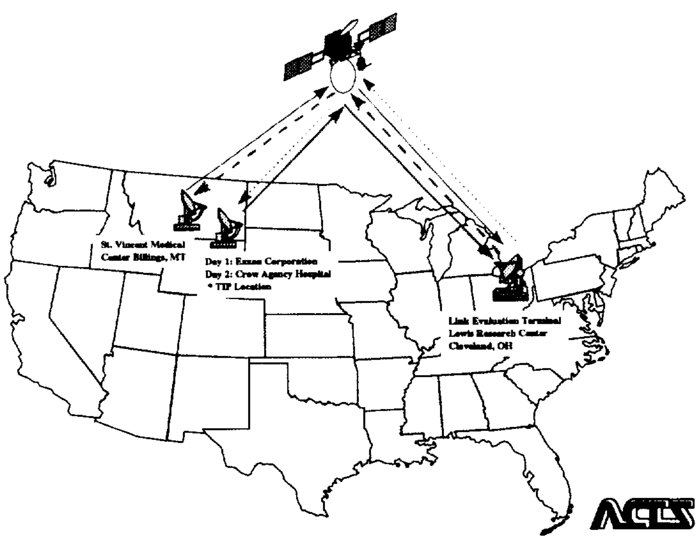

Figure 4 USAT locations for Telemedicine Demonstration

Both demonstrations were successful in introducing satellite technology to this particular rural area. The video quality and resolution at the T1 data rate was acceptable to the medical community for this type of application. Lower data rates would require additional testing and scenarios before reaching a consensus. The field medical personnel were not threatened by the new technology, but rather saw it as a benefit for certain circumstances when the choice to transport someone is difficult. It now gives them a second opinion to transport or not, thus saving significant costs for both patients and providers for unnecessary patient transports. In addition, in a community where linking medical centers together using terrestrial lines was a significant challenge, satellites were now a viable option to their communication infrastructure. In the words of one of the St. Vincent Medical Center personnel having never considered the use of commercial satellites; "satellites are now part of our vocabulary".

AIAA Satellite Conference, Washington, D.C. February, 1996

The demonstration at the AIAA Satellite Conference combined one way high rate compressed video at 23 Mbps from the Link Evaluation Terminal (Cleveland, Ohio) to the USAT (Washington, D.C.) while simultaneously providing two full duplex Basic Rate Interface (BRI) ISDN links, each at 160 Kbps. The compressed video source was received at NASA LeRC from a Ku-band satellite and retransmitted to the USAT at Ka-Band. The conversion from Ku-band to Ka-band and the satellite double-hop was transparent to the end user as no degradation was caused by the two satellite configuration. The two ISDN satellite links and the high rate video receive signal were separated in frequency within the 36 Mhz bandwidth of the USAT. Separate modems were used for the high rate link and each ISDN channel.

There were several devices supported by the ISDN connections. The first ISDN connection provided two ISDN telephones for conference attendees to place calls anywhere in the U.S. The hub side of this ISDN was connected to the PSTN at Lewis Research Center enabling people to place calls directly through the phone switch. The second ISDN link demonstrated two desk top video conferencing capabilities. The first was a British Telecom video conferencing unit and the second was a pc based desktop video conferencing system using Proshare software. Only one video system could be supported at a given time. Users could use the video conferencing systems to place a video call back to personnel at LeRC.

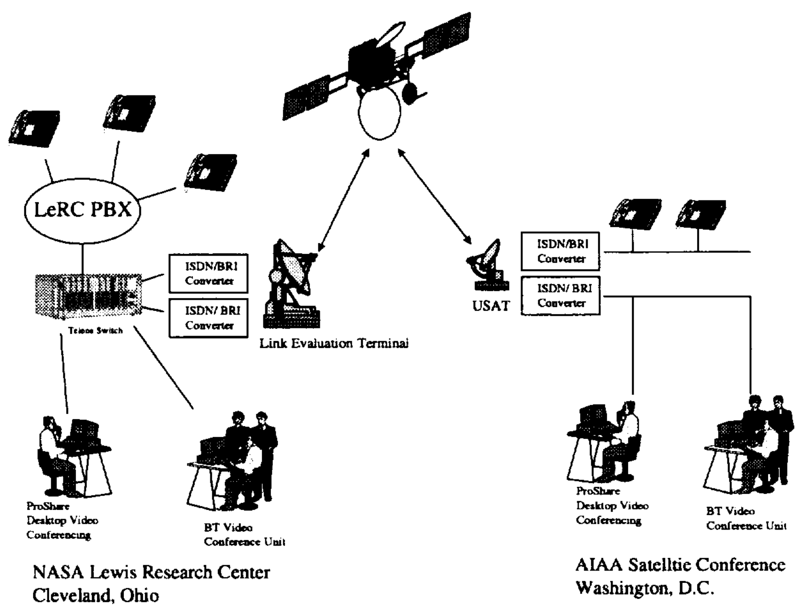

Figure 5 USAT ISDN via ACTS Satellite

The demonstrations were designed to allow people to experience the effect of the delay caused by both the ISDN video encoding equipment and geosynchronous satellites. The delay caused by the satellite is relatively small compared to the inherent delay in the ISDN video conferencing equipment. Telephone users perceived little delay and no echo. One of the largest criticisms of telephone over satellite has been the detection of echo of a users voice. Strides in echo cancellation equipment has provided virtually undetectable echo in the ACTS system. Figure 5 illustrates a system block diagram of the ISDN portion of the demonstration.

Pacific Telecommunications Conference, Waikiki Hawaii, January, 1997

Another demonstration of the USAT ground station occurred at the Pacific Telecommunications Conference in partnership with Lockheed Martin Telecommunications. In the first demonstration Lockheed Martin highlighted unidirectional high rate file transfer from the Link Evaluation Terminal in Cleveland, Ohio to the USAT at the conference location in Waikiki, Hawaii while simultaneously supporting a full duplex video conferencing link and remote control data link combined at T1 data rate.

Two sets of satellite modems configured at each site were used to complete the two satellite links. The first set of modems established the high rate link from the uplink facility at NASA LeRC to the USAT at the conference. This link supported the 8 Mbps data rate link for the file transfer. The second set of modems provided a full duplex T1 channel that provided MPEG (Moving Pictures Experts Group) video conferencing between the two sites. Of the 24 channels available, 23 were used for the video conferencing and one was reserved for the low rate return link for the remote site to request file transfers from the uplink facility. In this configuration, no action was required at the uplink facility for the file transfer.

This demonstration highlighted asynchronous high rate file transfer with a simultaneous modest data rate video and control link, using an FDMA configuration. This is a significant advantage of the USAT ground stations. The downlink bandwidth of the stations are currently 36 Mhz with larger bandwidth stations on the horizon. Having the wide bandwidth allows the USAT to receive information at higher data rates while a relatively low power transmitter allows uplink data rates on the order of T1 which is adequate for numerous video, voice, or data applications.

At the same time, NASA also conducted an ISDN demonstration at the conference supporting two individual 160 Kbps BRI ISDN video connections between the conference in Hawaii and LeRC in Cleveland. The configuration was similar to that demonstrated at the AIAA Conference. The USAT ground station supported both demonstrations simultaneously.

Technology 2006/Telecom XVI, Anaheim California, October, 1996

The Technology 2006 conference was held in conjunction with Telecon XVI at the Anaheim Convention Center. Technology 2006 was a NASA sponsored conference highlighting current technology developed and/or funded by NASA. To highlight the USAT technology, demonstrations were conducted at both the Technology 2006 and Telecon XVI conferences using two different USAT ground stations simultaneously with the Link Evaluation Terminal.

The first USAT demonstration at the Technology 2006 conference consisted of video conferencing at T1 data rate between two booths on the conference exhibit floor. This demonstration was a precursor to a formal telemedicine demonstration later in the conference and highlighted the video conferencing equipment and Ka-band link used in the demonstration. At the same time, another ACTS ground station known as a VSAT (Very Small Aperture Terminal) also at the conference site provided several ISDN video and voice links. Conference attendees were able to place ISDN calls from one video conferencing unit to another at the conference or back to LeRC personnel. People were also able to make ISDN telephone calls to any location. Evaluation was made on call quality, impact of satellite delay, and overall ease of operation. Most comments were supportive of the connection and most commented the satellite delay (when detectable) was acceptable compared to conventional terrestrial connections. For this demonstration ACTS was configured to provide access for both the USAT and VSAT to operate at the same time at the same location. This was the first time ACTS was used in this manner. Using both frequency separation and orthogonal polarization both ground stations were able to operate simultaneously for the demonstrations.

Another demonstration using a second USAT was held at Telecon XVI, also at the Anaheim Convention Center. Because the 4 Watt SSPA was used in the video conferencing demonstration, a 1 Watt SSPA with a 1.2m antenna was used for this demonstration. The demonstration was a combined high data rate MPEG video demonstration and low data rate interactive video conferencing system via the Internet, all over satellite. As shown in Figure 6, the

MPEG video demonstration begins by selecting a video or audio source at the source end (Link Evaluation Terminal) from the conference site. The selection is digitally encoded by an MPEG-2 encoder and the content transmitted back to the small ground station at the remote end via a 6 Mbps satellite link. A second satellite link using the same USAT ground station separated in frequency simultaneous operates from 76 kbps up to T1 data rate to extend the LeRC local area network out to a personal computer at the conference. The pc at the remote site provides the user remote control of the audio/video switch. A second pc on the remote end provides full duplex video conferencing using the Internet's popular CUSeeMe software for Internet video conferencing. The return data rate is determined by the ground station configuration, transmitter size, antenna size, etc. For this particular demonstration, 772 Kbps (½ T1) was used. The local pc also provides access to normal Internet Web browsing from the small USAT ground station via Ka-band satellite.

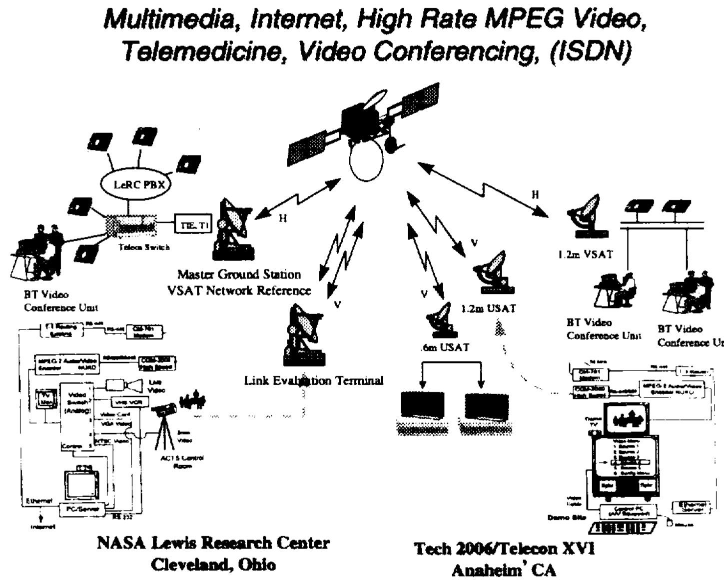

Figure 6 MPEG/Internet Video Conferencing Demonstration

Conclusion

As the FCC awards licenses to U.S. company's to build, launch, and operate Ka-band systems in the United States and around the world, NASA continues to play a vital role in providing a Ka-band system test bed available for use by U.S. industry. The ACTS Satellite managed and operated by NASA Lewis Research Center in cooperation with leading satellite communications industry partners, provides opportunity for organizations to test developing applications, system components, and other future technologies today, all at Ka-band. On-orbit demonstrations and experiments at Ka-band prove out technical designs, minimize technical risk in future systems, provides documented results and hands-on opportunities for the investment and business communities, and helps maintain U.S. industry capability at Ka-band.

NASA provides and maintains a series of Ka-band satellite ground stations available for use by experimenters. One such terminal, the Ultra Small Aperture Terminal (USAT) ground station uses a 35cm or 60cm antenna along with a modest solid state power amplifier transmitter ranging from a ¼ watt up to 4 watts to provide the necessary uplink power to accomplish a vast array of technical demonstrations across the U.S.

Several demonstration described here illustrate the capability and versatility of the USAT ground station. Demonstrations ranging from simple voice telephone calls, video conferencing, remote telemedicine applications, MPEG video distribution, remote control capability, Internet access from distant rural areas via satellite, to high speed file transfers all are possible from small and low cost satellite terminals.

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13. ABSTRACT ***(Maximum 200 words)***

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